CHAPTER 2

CAUSE OF DEATH AND LOCATIONS OF BIRD CARCASSES IN THE APWRA

2.1 INTRODUCTION

Our study of bird mortality and of fatality associations at wind turbines relied on finding carcasses and interpreting the condition of each to ascertain the circumstances of the bird's death. We also relied on a 50-m search radius around each wind turbine to include the majority of the carcasses resulting from collisions with wind turbines. In order to assess the efficiency of our search radius, we tested whether the distance of the carcass from the wind turbines related to the body size of the bird species, wind turbine attributes, season, and physiographic conditions. Understanding the factors that influence carcass search efficiency is important for interpreting our mortality estimates, as well as for designing future fatality monitoring programs at wind energy generating facilities around the world.

This aspect of our study was prompted by our discovery of carcasses beyond our search radius. Because we detected carcasses located beyond our search radius, we realized that some unknown proportion of the fatalities was not being detected because we were not systematically searching over a much larger area around each wind turbine. Also, we questioned the adequacy of our search radius as the repowering effort in the APWRA drew nearer. That program will result in the installation of a fewer number of much larger wind turbines on taller towers. We needed to know whether a greater search radius will be needed as part of the monitoring program following the repowering.

2.2 METHODS

The field methods used to find and record fatalities are described in Chapter 3. We identified each fatality by its associated carcass, or partial carcass, that was obviously independent of other evidence of fatalities in the area. We assumed that injured birds would eventually die as a result of their injuries, so they were also classified as carcasses, unless the injury was known to have healed and the bird returned to the wild.

Bird species were represented by typical body length (cm) as reported in National Geographic Society (1987), and were categorized as small (< 38 cm) or large (> 38 cm), the cutoff based on a natural break in a histogram of body length (Figure 2-1). We intended to factor in the slope of the hills downhill from each of the wind turbines, but we lacked sufficient funding to perform this step.

The statistical tests included mostly one-way analysis of variance (ANOVA) and least significant differences (LSD) between groups. All LSD tests reported below were associated with P-values < 0.05. We also estimated Pearson's correlation coefficient for the distance of the carcasses and elevation of the tower base.

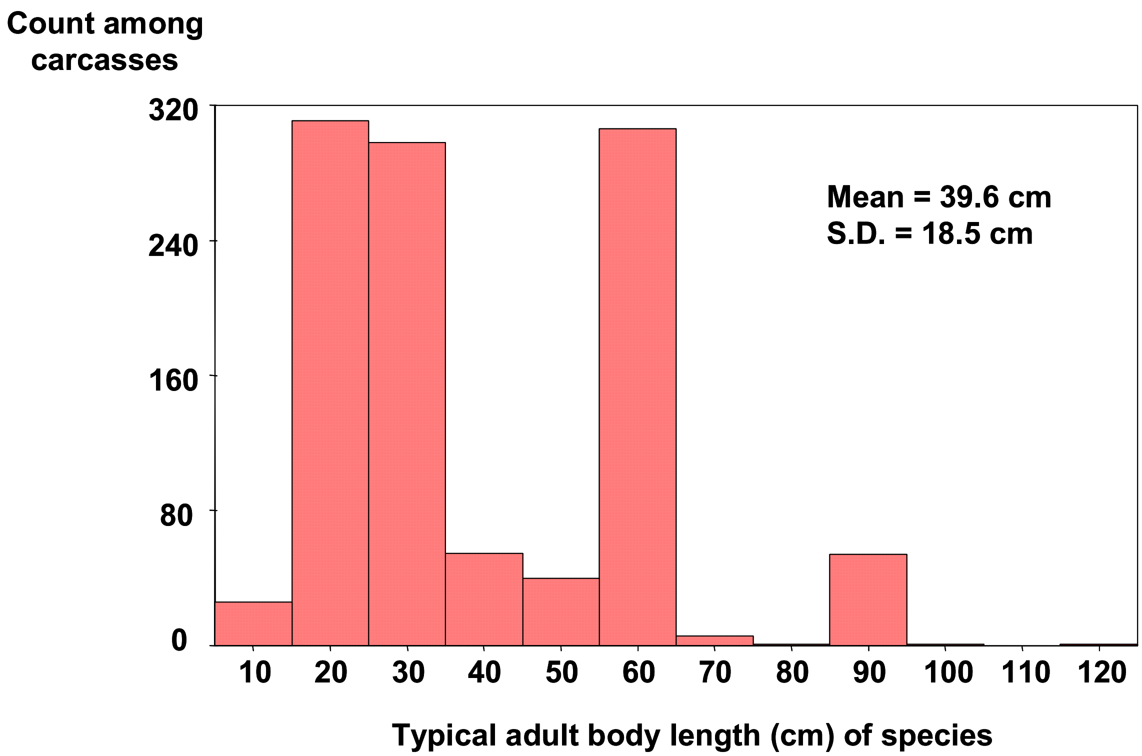

Figure 2-1. Frequency distribution of carcasses by typical body length of the species

2.3 RESULTS

2.3.1 Overview of Bird Fatalities in the APWRA

Most of the 1,189 carcasses we found in the study area were attributed to collisions with wind turbines, and the rest were attributed to predation, electrocution on electrical power distribution poles (e.g., Photo 2-1), collisions with wires and undetermined causes (Figure 2-2, Table 2-1). Broken and severed wings were the most common injuries noted, and decapitations, head injuries, and severe injuries to the torso were also common (Figure 2-3, e.g., Photos 2 through 5). However, many of the carcasses showed signs of multiple injuries, and these are not represented in Figure 2-3.

Age of the animal could not be estimated for most of the carcasses found, due to decomposition, and most of those that could be assigned an age category were adults, followed by immature birds (Figure 2-4). Most bird carcasses were discovered during summer and winter (Figure 2-5). Most were found near KCS-56 turbines on lattice towers and Bonus turbines on tubular towers (Figure 2-6), and most were estimated to have been killed within 30 days of discovery (Figure 2-7). Most were found in two ranges of elevation, between 115 and 225 m, and between 280 and 350 m (Figure 2-8).

We found evidence of 1,162 fatalities caused by collisions with wind turbines or their towers and by unknown causes (Table 2-1). Another 10 fatalities were caused by electrocution on electrical distribution poles and another two were caused by wire strikes. Two more carcasses were attributed to auto collisions as causes of death and 13 were due to predation.

Photo 2-1. A golden eagle electrocuted at an electrical distribution pole with riser elements

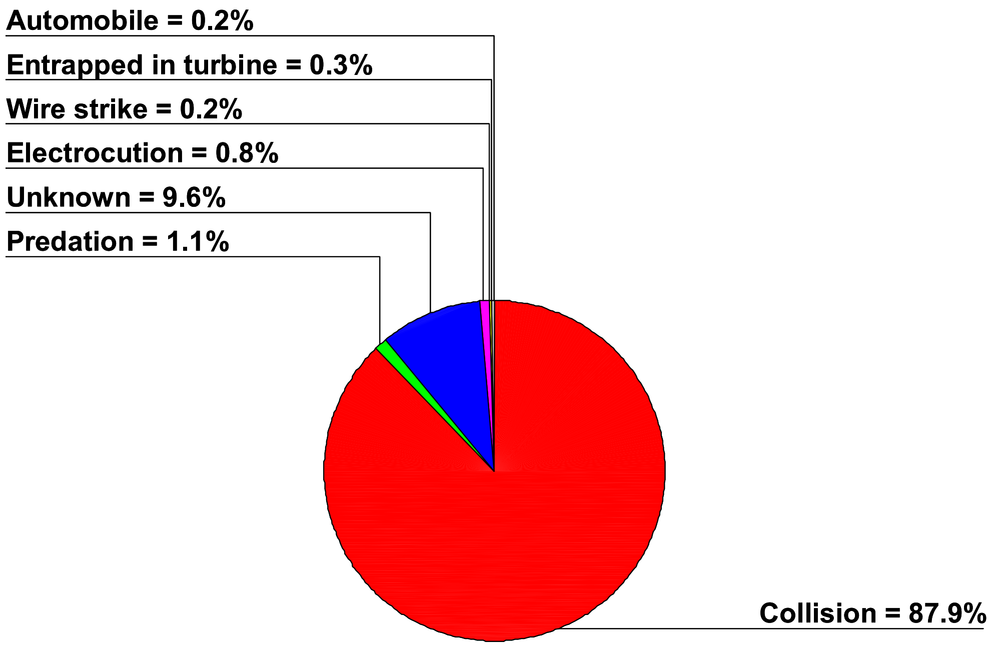

Figure 2-2. Pie-chart distribution of causes of fatalities attributed to carcasses found in the APWRA

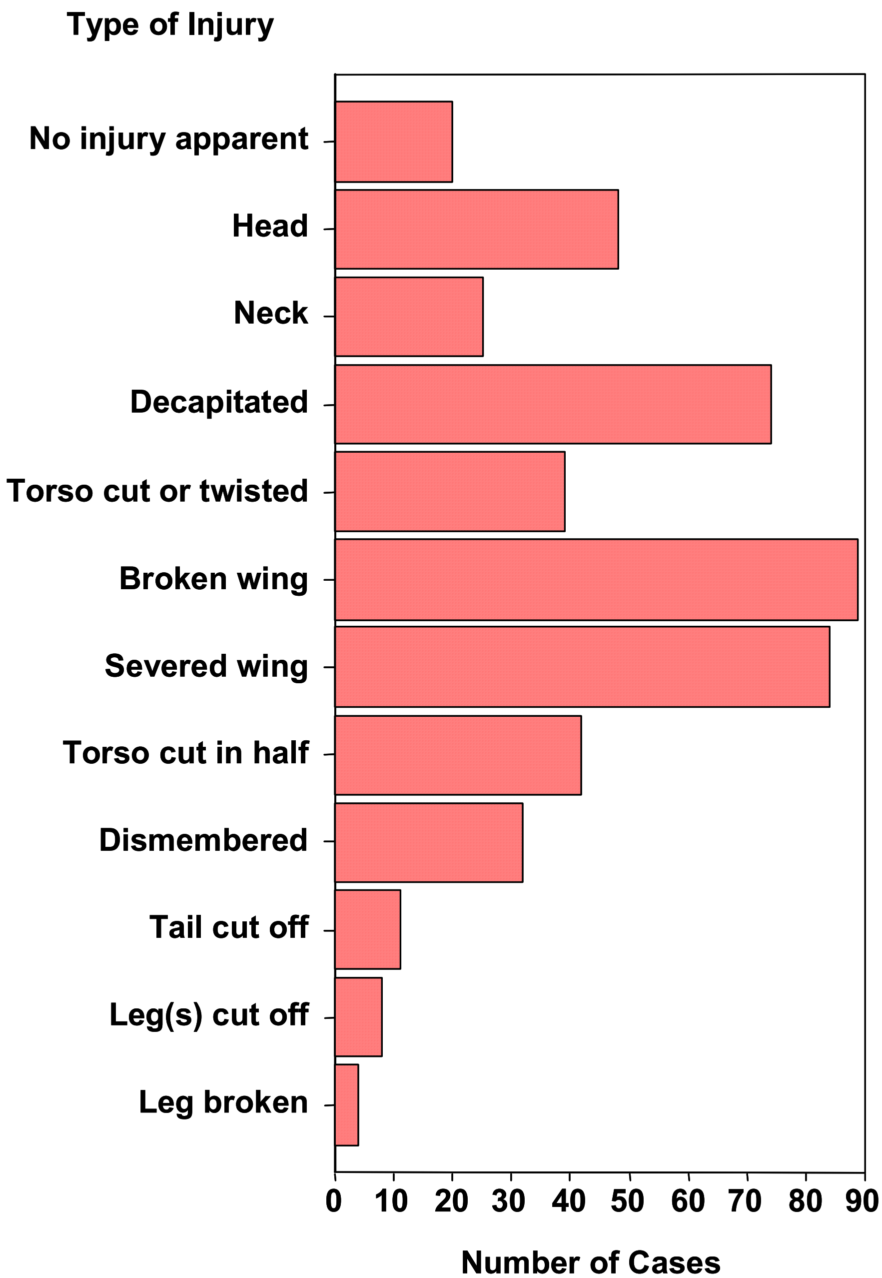

Figure 2-3. Frequency distribution of types of injury attributed to wind turbine-caused fatalities among birds found in the APWRA

Table 2-1. Summary of 1,189 bird (and bat) fatalities found in our study area from May 1998 through May 2003

Species/Group	Fatalities	Wind turbine collision	Electrocution	Wire strike
Golden Eagle	56	54	2	
Turkey Vulture	6	6		
Red-tailed Hawk	215	213	2	
Ferruginous Hawk	2	2		
Buteo sp.	24	24		
Northern Harrier	3	3		
White-tailed Kite	1	1		
Prairie Falcon	3	3		
American Kestrel	59	59		
Burrowing Owl	76	70		1
Barn Owl	52	50	1	1
Great Horned Owl	18	18		
Raptor	17	16	1	
Double-breasted Cormorant	1	1		
Cattle Egret	1	1		
Black-crowned Night Heron	2	2		
Lesser Yellowlegs	1	1		
American Avocet	3	3		
Mallard	36	35		
Ring-necked Duck	1	1		
Laridae sp. (gull)	18	18		
California Gull	7	7		
Ring-billed Gull	4	4		
Northern Flicker	6	6		
Mourning Dove	35	34		
Rock Dove	196	196		
Wild Turkey	1	1		
Northern Mockingbird	1	1		
Say's Phoebe	1	0		
Western Kingbird	1	1		
Pacific-slope Flycatcher	1	1		
Horned Lark	23	23		
Western Meadowlark	99	96		
Common Raven	12	12		
Tricolored Blackbird	1	1		
American Crow	7	5	2	
Brewer's Blackbird	13	13		
Red-winged Blackbird	12	12		
Brown-headed Cowbird	2	2		
Blackbird *(Icterinae sp.)*	1	1		
European Starling	67	67		

Table 2-1. (cont'd)

Species/Group	Fatalities	Wind turbine collision	Electrocution	Wire strike
Loggerhead Shrike	5	5		
Cliff Swallow	5	5		
Mountain Bluebird	5	5		
Violet-green Swallow	1	1		
Townsend's Warbler	1	0	1	
Black-throated Gray Warbler	1	0	1	
Yellow Warbler	1	1		
Savanna Sparrow	2	2		
House Finch	18	14		
House Sparrow	1	1		
Cockatiel	1	1		
Passerine	16	16		
Unknown	42	42		
Hoary Bat	4	3		
Totals	**1,189**	**1,162**	**10**	**2**

Photo 2-2. A decapitated American kestrel found under a wind turbine

Photo 2-3. A mallard cut in half by a wind turbine

Photo 2-4. The wing of a golden eagle found under a wind turbine

Photo 2-5. A golden eagle cut in half by a wind turbine

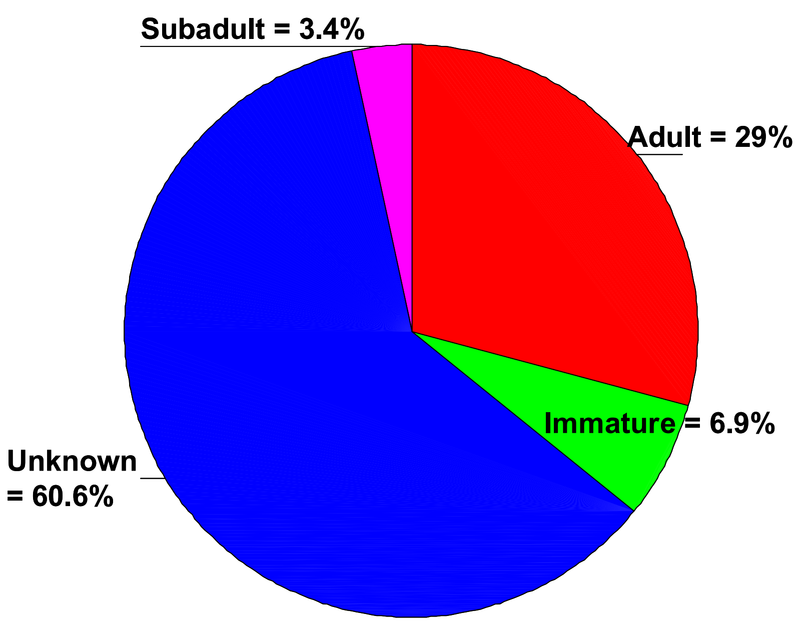

Figure 2-4. Pie-chart distribution of age classes of birds killed by wind turbines in the APWRA

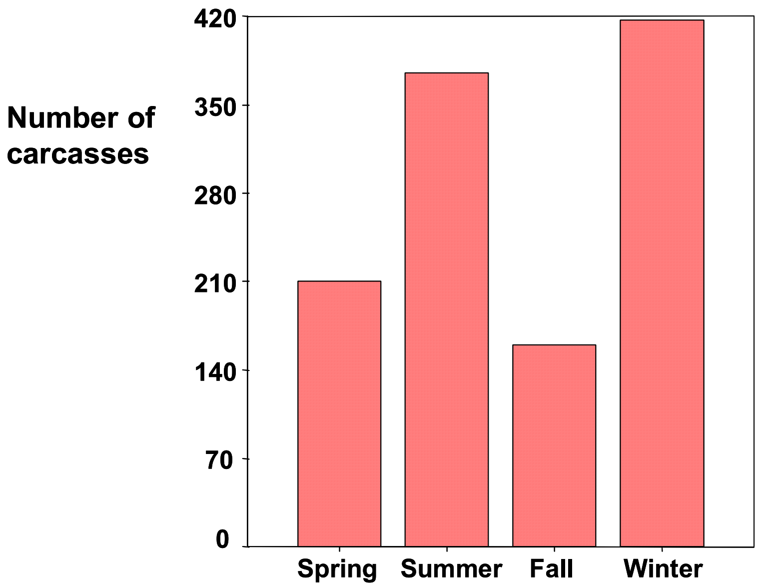

Figure 2-5. Number of bird fatalities found per season

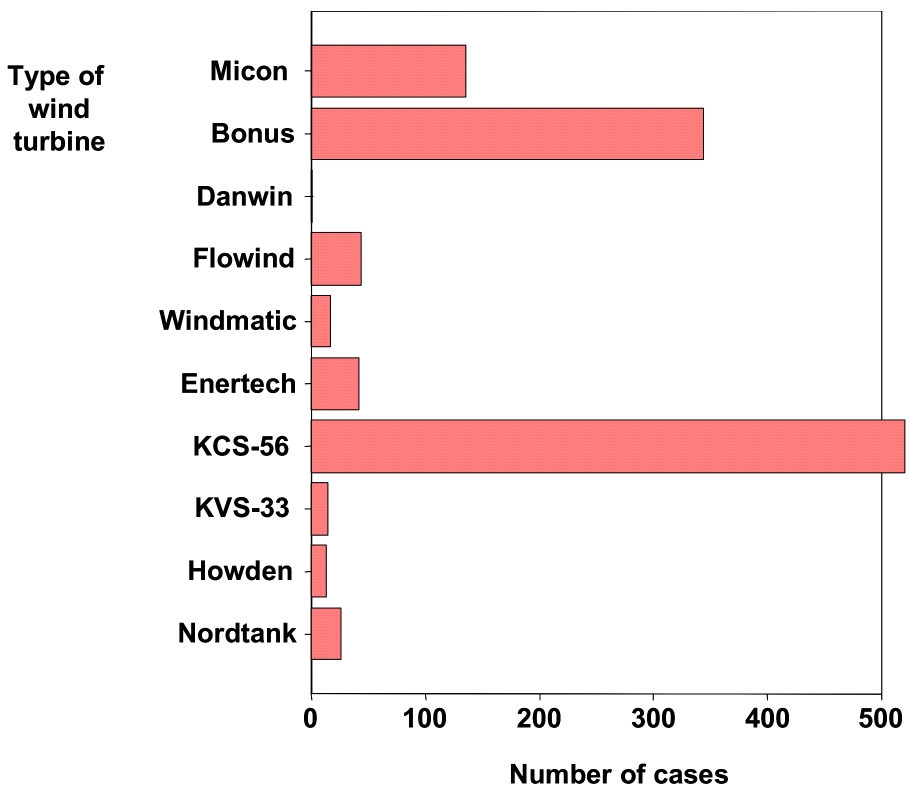

Figure 2-6. Number of bird carcasses found next to each wind turbine model surveyed in the APWRA

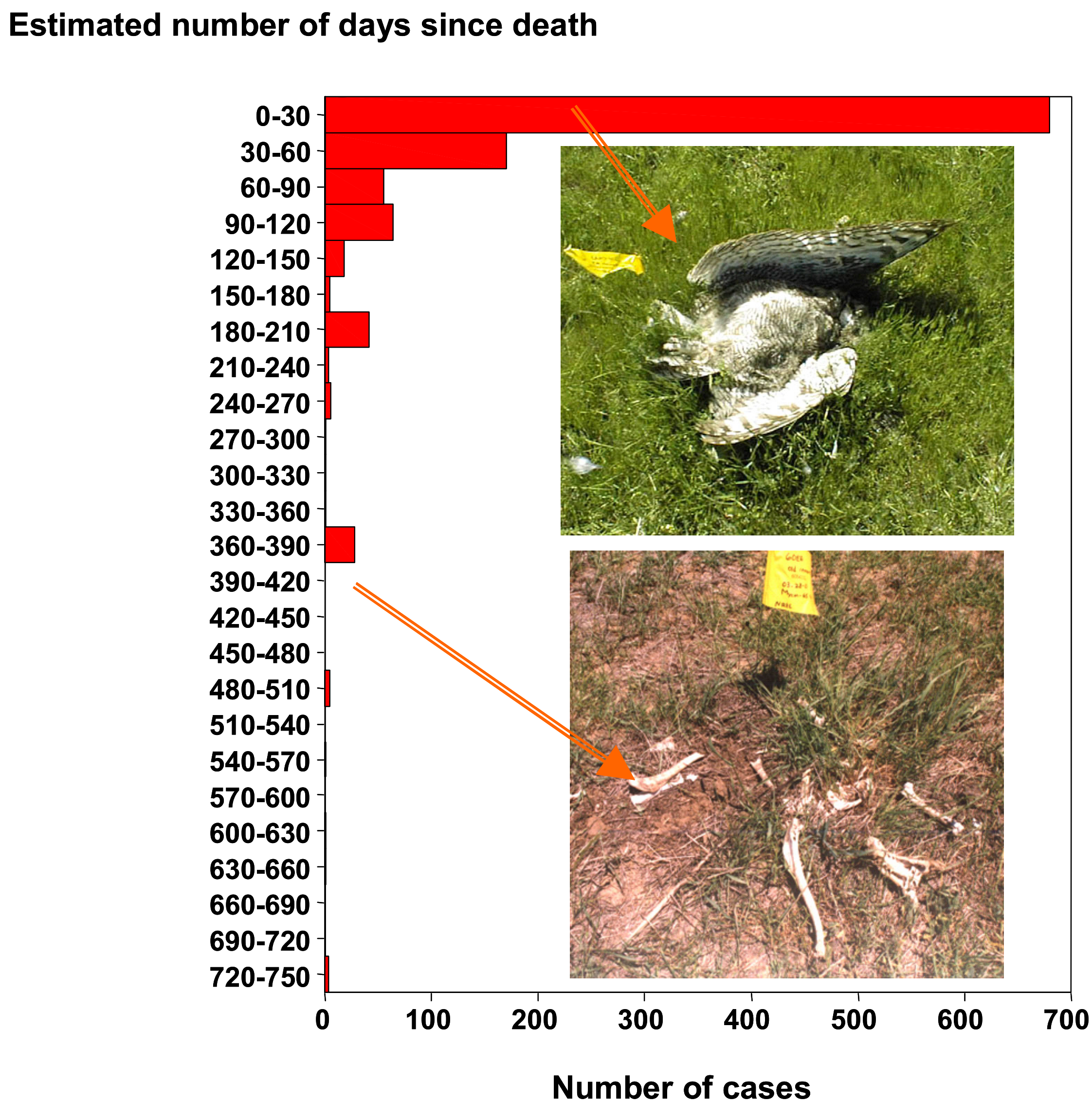

Figure 2-7. Frequency distribution of estimated number of days since death caused by wind turbines in the APWRA

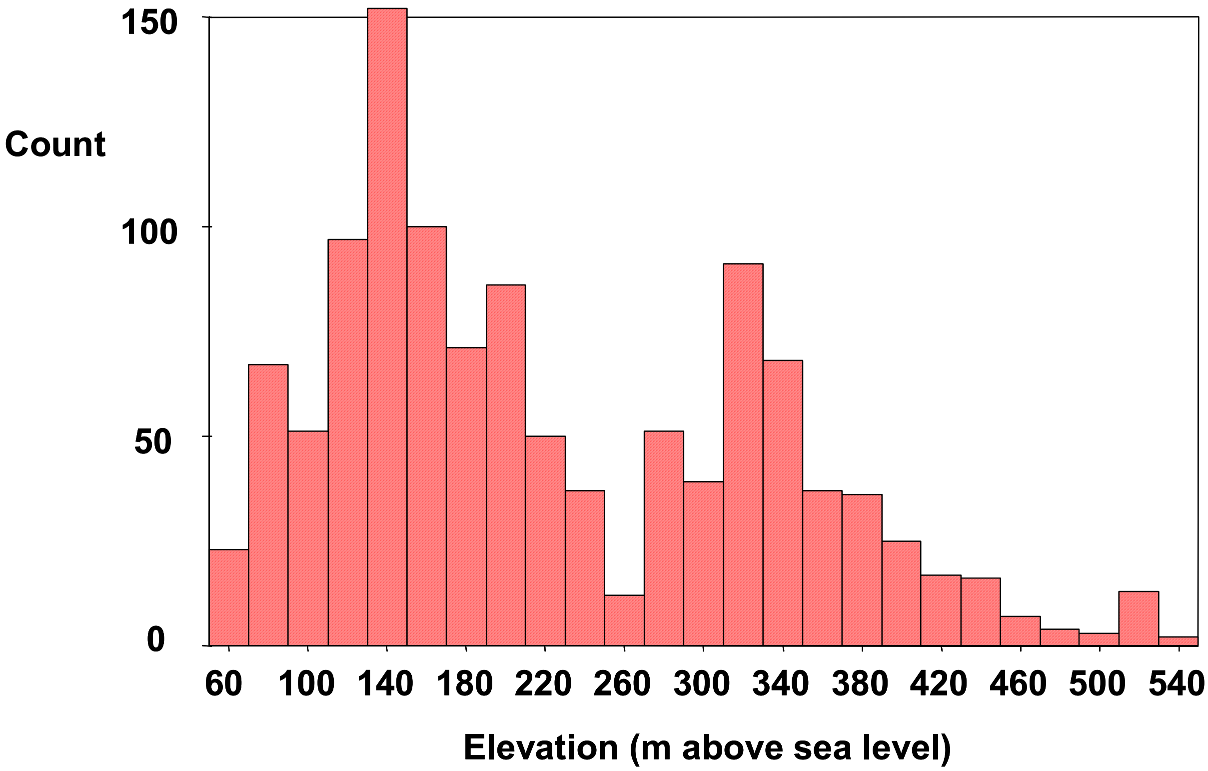

Figure 2-8. Frequency distribution of wind turbine-caused fatalities found in the APWRA (by elevation)

2.3.2 Distances of Bird Carcasses from Wind Turbines

Large-bodied Birds

Our search radius included 84.7% of the carcasses of large-bodied bird species determined to be killed by wind turbines or unknown causes (Figure 2-9A). Of these, 75% were located within 42 m of the tower. The mean and standard deviation of these 468 distances was 31.1 ± 30.0 m. Most carcasses were found northeast of the tower, and a considerable number were located southwest of the tower (Figure 2-10A).

Carcass locations of large-bodied bird species differed significantly by distance from wind turbines according to five ranges of tower heights (ANOVA $F = 3.66$; $df = 4, 456$; $P = 0.006$), and post-hoc LSD tests revealed that fatalities were located farther from 25-m and 32-m towers (means = 33 m and 57 m) than shorter towers (mean = 28 m for 14-m towers, and 26 m for 18.5-m towers) or 43-m towers (mean = 28 m). Distance from tower increased with tower height, according to linear regression analysis, although the precision of the model was poor (Figure 2-11A).

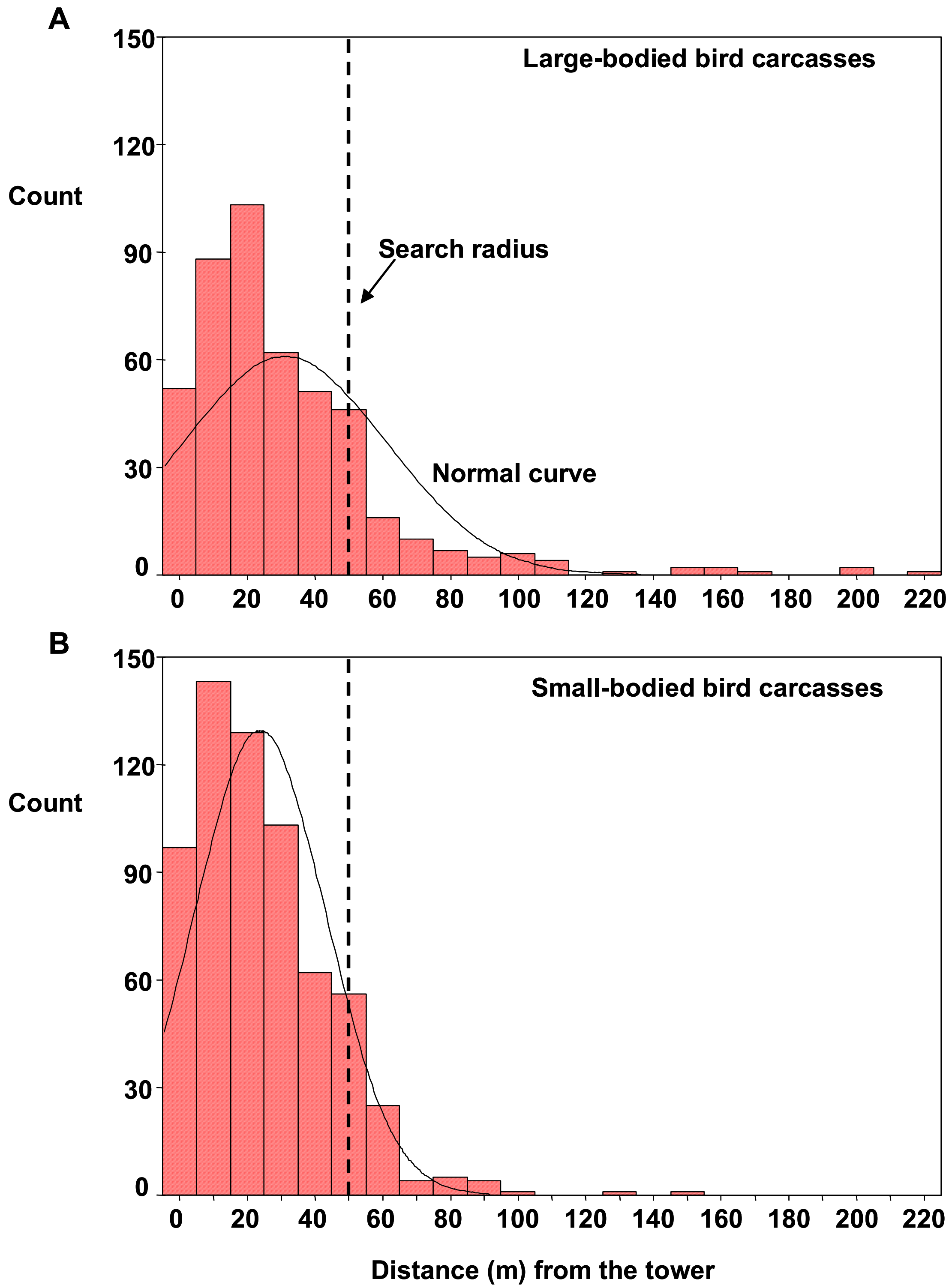

Figure 2-9. Frequency distributions of distance from the wind tower among carcasses of large-bodied (A) and small-bodied (B) bird species

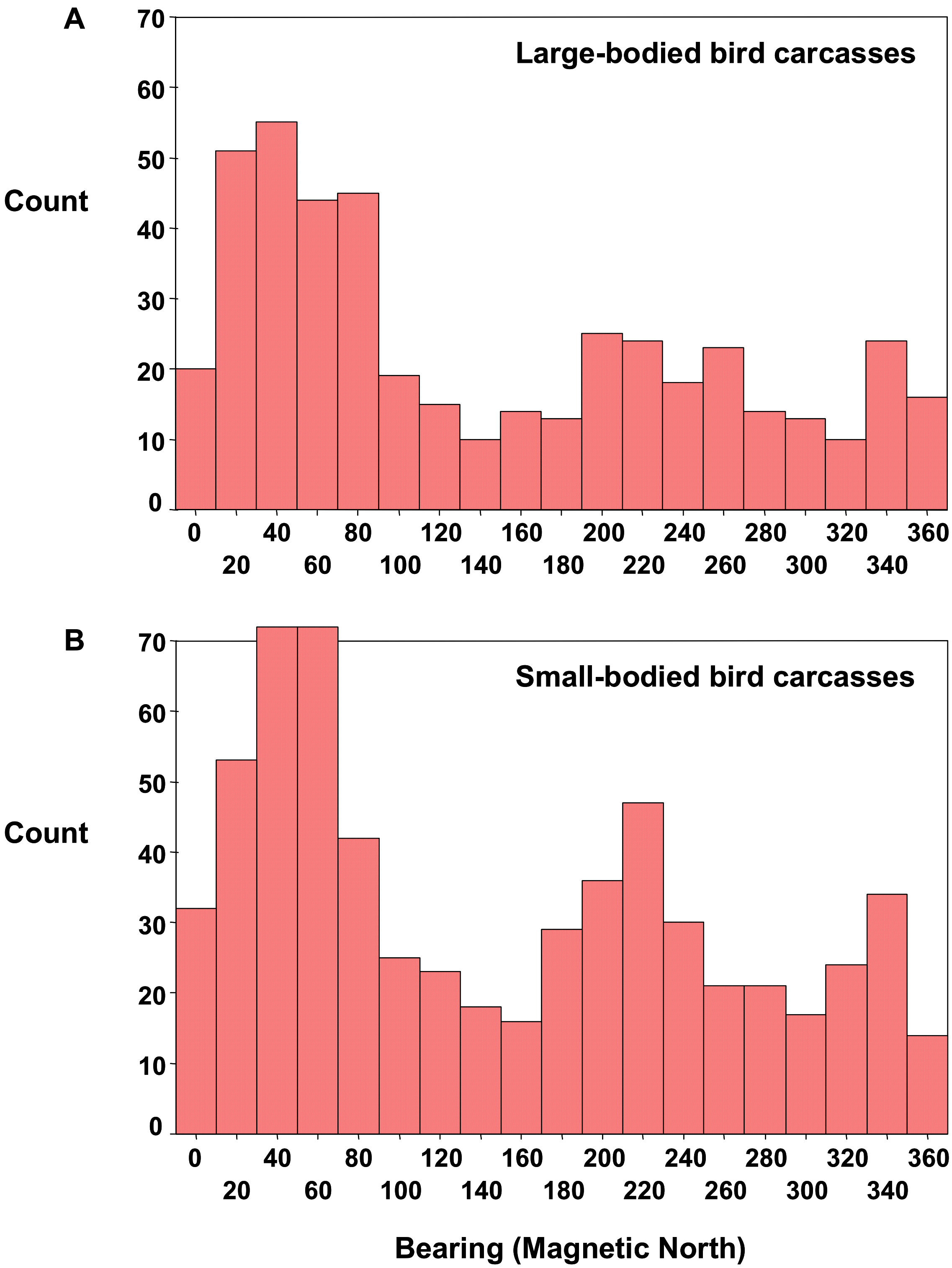

Figure 2-10. Frequency distributions of bearing from the wind tower among carcasses of large-bodied (A) and small-bodied (B) bird species

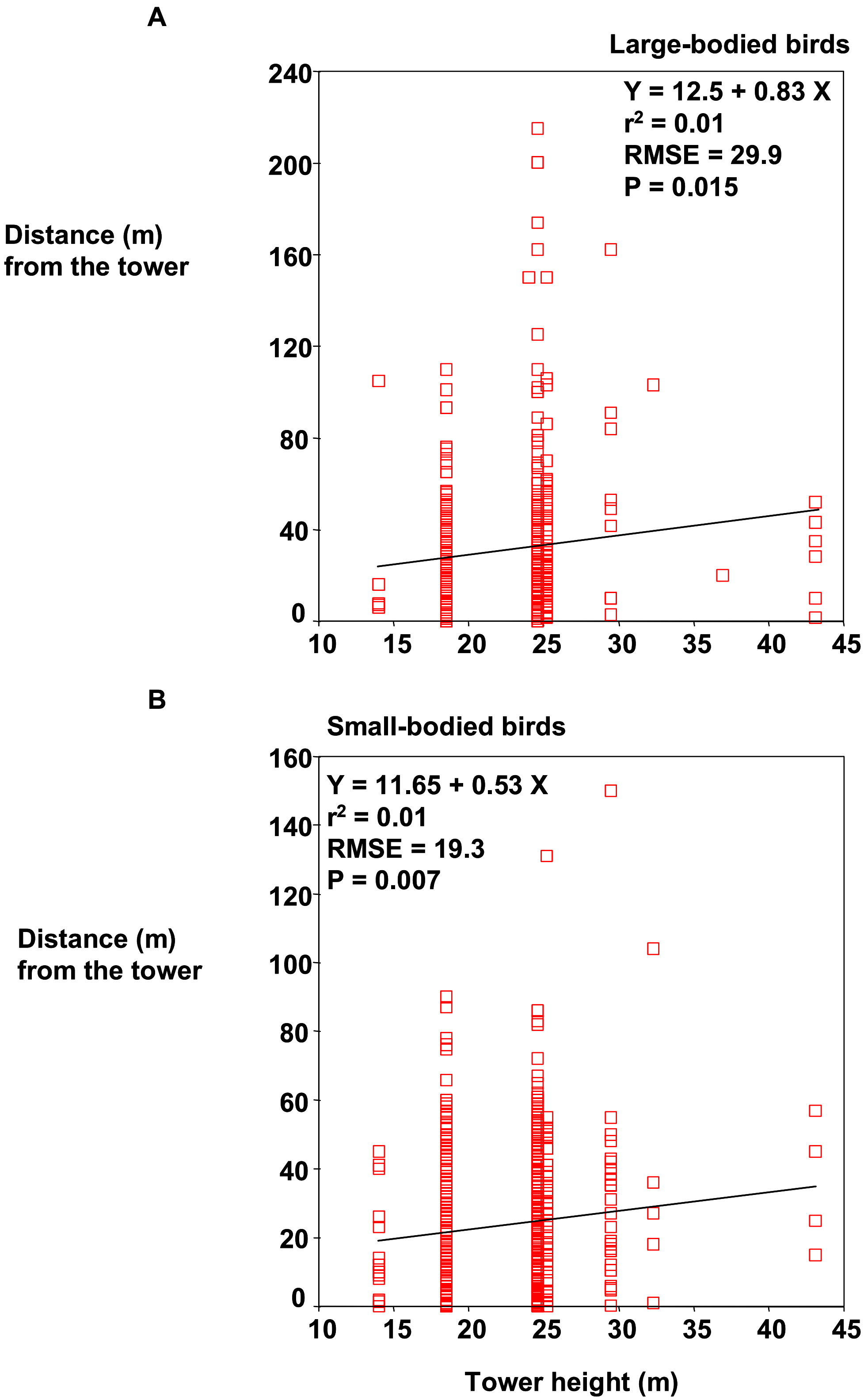

Figure 2-11. Distance of the carcass from the wind tower was a positive linear function of tower height for both large-bodied (A) and small-bodied (B) bird species.

We found that carcass distances from wind turbines differed significantly, based on blade tip speed (ANOVA $F = 3.72$; $df = 9, 455$; $P < 0.001$), although LSD tests revealed that the differences were only due to two turbine models operating at intermediate-fast speeds and otherwise there was no gradient from slow to fast speeds. The distance of the carcass location did not differ significantly by whether the rotor faces upwind or downwind (ANOVA $F = 2.61$; $df = 1, 446$; $P = 0.107$).

The distance of carcass locations from the wind turbines differed according to whether the wind turbine was located at the end, at a gap, or in the interior of a string of towers (ANOVA $F = 11.11$; $df = 2, 455$; $P < 0.001$), and post-hoc LSD tests found distances to be 13 m greater on average from end and edge of gap turbines, compared to interior turbines. Figure 2-13 illustrates the differences between mean distances.

Carcass distance from wind turbine did not differ by season of the year (ANOVA $F = 0.75$; $df = 3, 458$; $P = 0. 524$).

The distance of carcass locations from the wind turbines did not differ according to whether the wind turbine was located in a canyon (ANOVA $F = 0.15$; $df = 2, 456$; $P = 0.862$). It did not differ by four ranges of slope grade (ANOVA $F = 1.25$; $df = 3, 456$; $P = 0.291$), and it did not correlate significantly with elevation ($r_p = -0.03$, $n = 457$, $P = 0.463$).

Small-bodied Birds

Our search radius included 90.5% of the carcasses of small-bodied bird species (Figure 2-9B), of which 75% were located within 34 m of the tower. The mean and standard deviation of these 631 distances was 23.8 ± 19.4 m. Most carcasses were found northeast of the tower, and a considerable number were located southwest (Figure 2-10B), just as the large-bodied bird carcasses had been distributed.

Carcass distances from wind turbines tended to differ according to five ranges of tower height (ANOVA $F = 2.24$; $df = 4, 628$; $P = 0.064$), and post-hoc LSD tests indicated that carcasses were more distant from increasing taller towers through 32-m tower heights (mean distances at 14-, 18.5-, 25-, 32-, and 43-m heights were 17, 22, 24, 31, and 36 m, respectively). A linear regression slope was significant but imprecise (Figure 2-11B), and it predicted that for every meter increase in tower height, average distance of the carcass from the tower increased by half a meter.

Distance between carcass and tower did not differ significantly by wind turbine model (ANOVA $F = 1.68$; $df = 8, 628$; $P = 0.101$) (also see Figure 2-12B), or by blade tip speed (ANOVA $F = 1.446$; $df = 10, 628$; $P = 0.156$), or by whether the rotor faces upwind or downwind (ANOVA $F = 0.98$; $df = 1, 596$; $P = 0.322$).

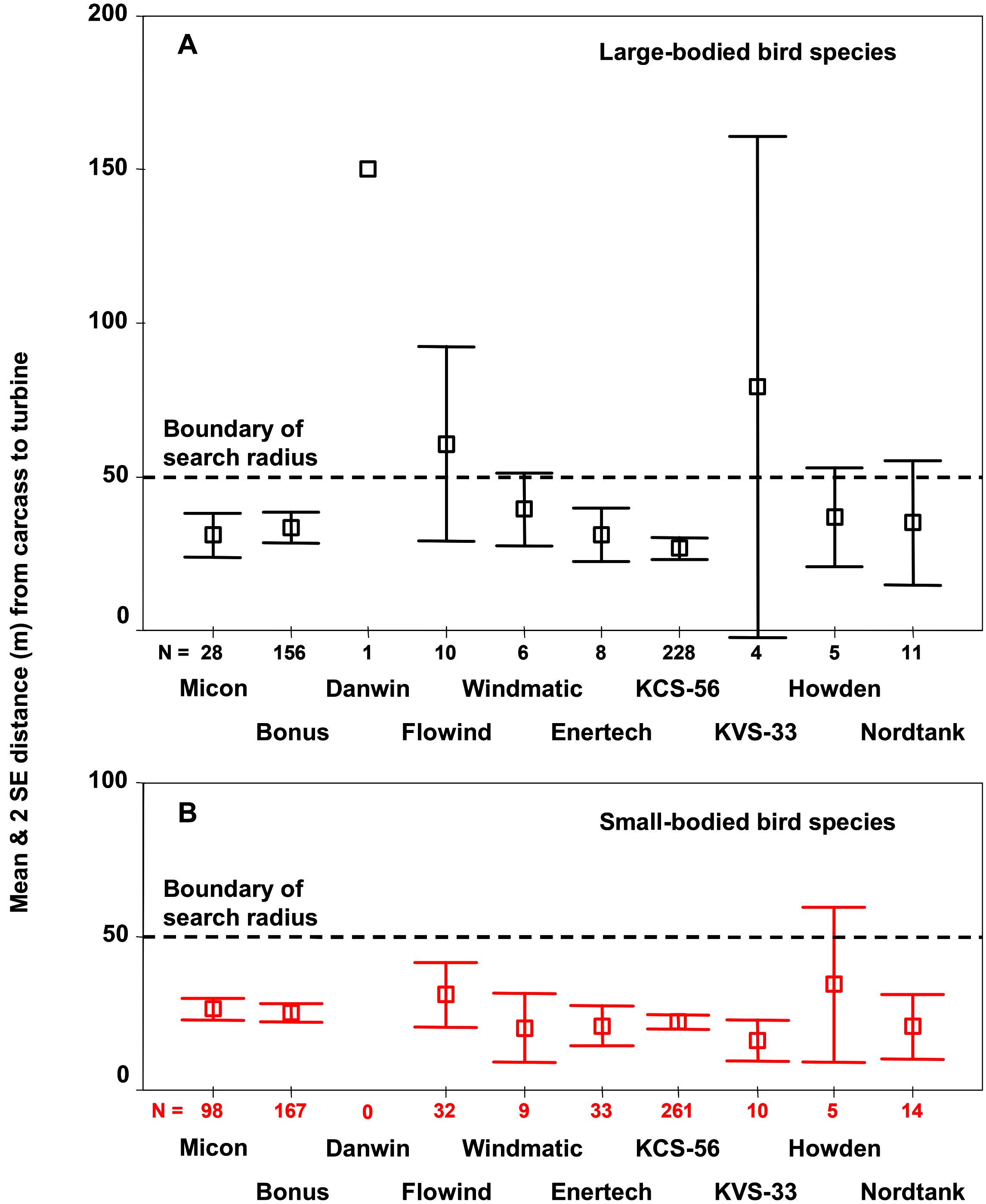

Figure 2-12. Mean distances from models of wind turbines for large-bodied (A) and small-bodied (B) bird species

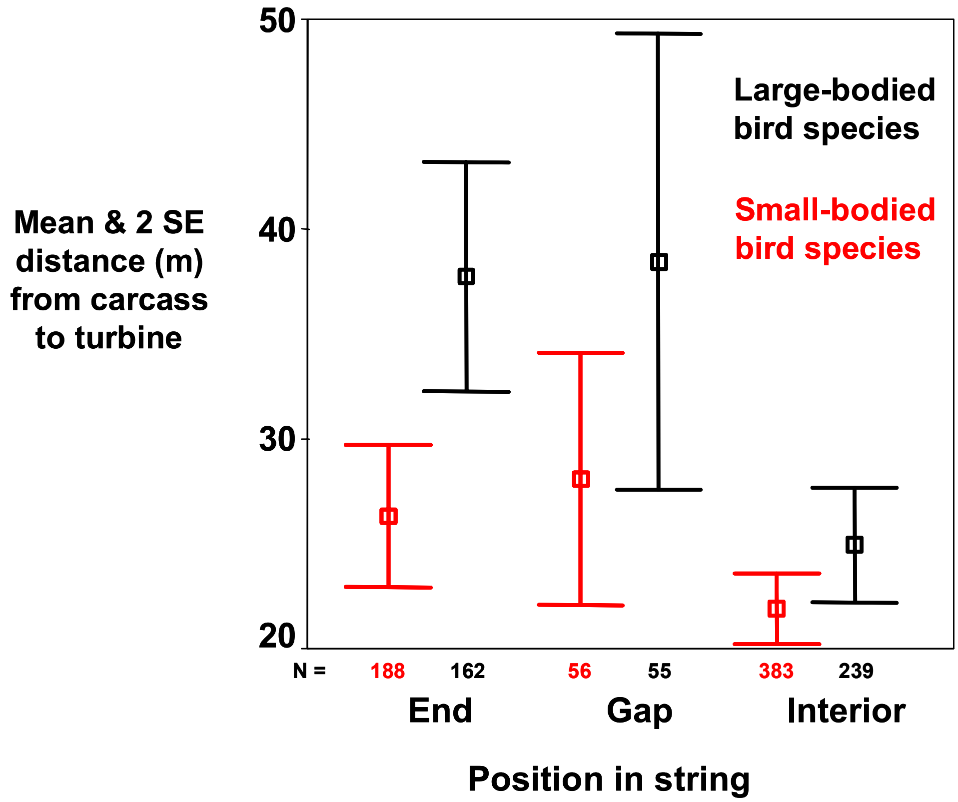

Figure 2-13. Mean distances of bird carcasses from wind turbines according to their positions in the string

Distance between carcass and tower differed significantly by position of the wind turbine in the string (ANOVA F = 4.79; df = 2, 626; P = 0.009), and post-hoc LSD tests revealed that the mean distances from end and edge-of-gap turbines were 4.4 m and 6.2 m greater, respectively, than from interior turbines.

Carcass distances from wind turbines differed significantly by season of the year (ANOVA F = 3.61; df = 3, 630; P = 0.013), and post-hoc LSD tests revealed that fatalities in spring were significantly closer to wind turbines (mean = 19.6 m) than were fatalities during summer (mean = 24.8 m), fall (mean = 28.1 m), and winter (mean = 23.5 m).

The distance of carcass locations from the wind turbines did not differ according to whether the wind turbine was located in a canyon (ANOVA F = 1.82; df = 2, 628; P = 0.164), or by four ranges of slope grade (ANOVA F = 0.237; df = 3, 628; P = 0.871). It correlated significantly and inversely with elevation, although the correlation coefficient was not large (r_p = -0.08, n = 628, P = 0.038).

2.4 DISCUSSION

We found birds beyond the 50-m search radius because the search crew members could sometimes see carcasses at these greater distances as they approached the 50-m termini of their transect segments. We found 15.3% of the carcasses of large-bodied species in our sample beyond the 50-m search radius, and 9.5% of our sample of small-bodied species was beyond our search radius. It appears that either larger-bodied bird carcasses were more readily seen at distances beyond the search radius or the majority of small-bodied birds truly fell within the 50-m search radius. We assume that we did not find an unknown proportion of the actual population of carcasses, due to carcasses located beyond our search radius.

Table 2-2 summarizes the results of our statistical tests of carcass distances related to measured variables. Taller towers knocked carcasses farther from the wind turbines, as did Flowind and KVS-33 wind turbines.

Table 2-2. Summary of significant test results related to distances of carcasses of large-bodied bird species from wind turbines

Variable	Large-bodied	Small-bodied
	Carcass distances greater at:	
Tower height	Taller towers	Taller towers
Turbine model	Flowind and KVS-33	---
Position in string	End and gap towers	End and gap towers

Although the position of the wind turbine in the string related significantly to the distance of carcass from the tower, the effect should be expected, simply because there is greater opportunity for carcasses to be located farther from the end tower. That is, if a bird is killed by an interior turbine, its carcass is likely to fall to either side and to be associated with the neighbor tower; whereas, the end tower only has one neighbor for such a mistaken association to be made. Still, the percentage of carcasses of large-bodied bird species found within 50 m of end turbines was 79%, which was 6% fewer than all the towers considered together and 11.4% fewer than the interior turbines alone. A greater search effort is needed for large-bodied bird species at end turbines; 100 m would include 94% of the carcasses we found.

A shortfall of our study was that we did not factor in the slope of the hills downhill from where the towers are located. The slope of the hills to each side of the wind turbines should be characterized and linked to the locations of the fatalities, so that measured distances from wind turbines can also be transformed into horizontal, planar distances by accounting for the degree of slope between the carcass and the tower. Many of the wind turbines at the ends of strings are located on precipices of very steep hills descending into ravines and canyons; they occur at the break of convex slopes. Birds can fall down these steep slopes, resulting in greater measured distances from the wind turbine. This potential effect needs to be considered in the future.